
VOLUMETRIC AND MARSHALL PROPERTIES OF HOT MIX ASPHALT WITH LDPE-MODIFIED BITUMEN, HIGH RECLAIMED ASPHALT CONTENT PAVEMENT AND WASTE ENGINE OIL

**Abdulummin Ahmed Shuaibu¹, Mudassir Rabi Adam^{2,*}, Ahmad Abdulsalam Amin¹,
Esther Amanosi Nyebe^{1,3}, Asmau Hamdana Kankia⁴, Abdulummin Nda Mohammed^{1,5},
Ismaila Mohammed Amodu^{1,6}**

¹Department of Civil Engineering, Ahmadu Bello University, Zaria

²Department of Highway Engineering, Federal University of Transportation, Daura

³School of Civil Engineering, University of Manchester, Oxford Road, Manchester, UK

⁴Office of the Secretary of Kaduna State Government, Kaduna State

⁵Department of Civil Engineering Faculty of Engineering, Baze University, Abuja

⁶Julius Berger Nigeria, Ltd, Abuja, Nigeria

Email: abdulshub4u@gmail.com, mradam2439@gmail.com*, abdulsalamahmad017@gmail.com,
esther.nyebe@manchester.ac.uk, asmauhamdana@yahoo.co.uk,
abdulummin.mohammed@bazeuniversity.edu.ng, ismaila.amodu@julius-berger.com

***Corresponding author:** Mudassir Rabi Adam

DOI: <https://doi.org/10.67203/sp.ICESID.2026>

ABSTRACT

The use of Reclaimed Asphalt Pavement (RAP) in Hot Mix Asphalt (HMA) is as a result of the growing need for economical and environmentally friendly road construction solutions. When old asphalt is removed for resurfacing and reconstruction, RAP is created. Furthermore, the rise in plastic garbage in recent years has become a major ecological problem on a global scale. Therefore, this study explores the volumetric and Marshall properties of HMA containing High RAP proportion, Low-Density Polyethylene (LDPE) modified bitumen and Waste Engine Oil (WEO) as a rejuvenator. Preliminary physical property testing was conducted on the HMA constituent materials in accordance with the relevant standards. The Marshall mix design was employed to determine the optimum binder content of the control mix using virgin materials with varying bitumen content from 5% to 7% at 0.5% intervals. Furthermore, RAP in the varying proportion of 25% to 100% at an interval of 25% was introduced to replace the virgin coarse aggregates by weight (25%, 50%, 75%, and 100%) with LDPE Modification at varying replacement level from 4% to 12% at an interval of 4% by the weight of bitumen. A 15% of WEO by the weight of the optimum binder content was added to the mix as rejuvenator. Although some combinations containing 100% RAP exceeded the flow restrictions, the Marshall stability and flow values of the examined mixtures meet the requirement of >3.5 kN and 2-4mm respectively. Moreover, majority of the assessed volumetric properties of the mixes did not meet the established standards. These findings suggest that using high RAP contents, LDPE-modified bitumen and WEO has a potential to produce HMA with acceptable Marshall stability. However, in order to achieve satisfactory volumetric characteristics and complete compliance with specifications, there is need for further study to optimize the binder content, WEO dosage, LDPE concentration.

Keywords: Marshall Properties; reclaimed asphalt; low-density polyethylene; hot mix asphalt and waste engine oil

1.0 INTRODUCTION

Road infrastructures are important lifelines for modern societies, in Nigeria, socioeconomic developments are directly related to quality roads. According to FMWH (2013), the total national road network is approximately 200,000 km and only about 65,000km of the 200,000km are flexible pavements which represent about 33% of the entire road network. Flexible pavements are most commonly used for low to medium volume roads with significant usage also found in high volume interstate highways and airfield runways, taxiways and aprons subjected to heavy aircraft gear/wheel loads (Mohod and Kadam, 2016).

In recent years, however, growing environmental concerns have led many industrial and societal sectors to change their policies around waste management, resource use, and the efficiency of

production of goods and services. As we strive for a circular economy and sustainable resource use, it is becoming increasingly crucial to reuse and recycle non-renewable resources, as a result, the construction and maintenance of transportation infrastructure, in particular, is gradually adopting eco-friendly technology to reduce its ecological impact (Cheraghian *et al.*, 2020)

In this context, the intensive extraction and processing of virgin materials for asphalt production significantly disrupt natural habitats and degrade ecological systems. Researchers have been investigating the possibility of finding suitable sustainable materials that can be used in replacement of conventional pavement materials. Arianto *et al.* (2019) reported recycling of the used pavement materials as a technique for pavement rehabilitation as it conserves energy and resource. Recycling and reusing of non-renewable materials are becoming increasingly imperative in order to move towards a circular and sustainable economy as well as a sustainable use of resources. In particular, the industry of construction and maintenance of transport infrastructures is gradually applying environmentally friendly solutions, aiming to reduce its ecological footprint (Rodrigues *et al.*, 2020).

Among the available sustainable approaches, most popular technique is recycling RAP back into hot mix asphalt (HMA). The addition of RAP to new asphalt mixtures made using different manufacturing processes, such as hot, warm, half-warm, and cold-mix asphalt, is one of the most popular recycling techniques in pavement construction and maintenance (Rodrigues *et al.*, 2020). Martinho *et al.* (2018) reported some potential benefits of using reclaimed asphalt such as reducing the quantity of demolition trash that is dumped in landfills, cutting down on energy consumption and emissions and lowering the need for more non-renewable raw materials. Additionally, it has been shown to reduce issues of waste disposal and the likelihood of cracking and rutting while increasing the stiffness and resistance of asphalt to deformation (Ozer *et al.*, 2009).

Despite these benefits, the introduction of RAP into a new asphalt mixture can create challenges because the aged RAP binder can significantly influence the properties of the resulting mixture, particularly when recycling involves high percentages. The incorporation of RAP as a constituent in the production of fresh asphalt mixtures causes some challenges having been the bitumen suffers short- and long-term ageing such as oxidation and volatilization of constituents as reported by Hunter *et al.* (2015) and Rodrigues *et al.* (2020).

To address these limitations, fresh bitumen or any other rejuvenating agent can be incorporated to partially recover the lost properties of the aged asphalt binder. To recover the desired properties of the aged binder, an appropriate amount of fresh bitumen or rejuvenator is added to a satisfactory level of performance. Consequently, the rejuvenator ability to reactivate the aged binder is of major importance to achieve adequate performance of the asphalt mixture (Rodrigues *et al.*, 2020).

Among the potential rejuvenating materials, Waste Engine Oil (WEO) is particularly relevant because enormous quantities are generated worldwide by cars, trucks, trains, airplanes, generators, industries, and other machinery (Khurshid *et al.*, 2021). Waste engine oil (WEO) has gained increasing attention as a potential rejuvenator for high-RAP asphalt mixtures due to its physicochemical resemblance to the maltene fraction of bitumen. WEO, rich in light hydrocarbons and aromatic fractions, can partially compensate for this depletion by restoring the maltene–asphaltene balance (Fathi *et al.*, 2026). Onuche *et al.* (2024) reported that Nigeria consumes about 700 million litres of lubricants annually from which about 80% WEO is generated with potential of production of 336 million litres per year of diesel like fuel. Therefore, effective management and beneficial reuse of this waste is of paramount importance in mitigating environmental pollution that may eventually endanger human health and ecosystem.

Additionally, polymer modification provides another approach for improving the performance of bituminous materials. Bitumen is known to degrade over time due to a number of factors, including volatilization and component oxidation. Polyethylene has been found to be one of the greatest polymer additives as it is the most commonly used plastic worldwide (Nizamuddin *et al.*, 2021). Simultaneously, the increasing generation of plastic waste presents a significant environmental challenge. Ezeudu *et al.* (2024) reported an estimated figure of about 27.3 million tonnes of municipal solid waste currently generated in Nigeria's urban cities per annum about 11.2 million tonnes is collected of which about 1.1 million tonnes is plastic.

Beyond these environmental considerations, the use of suitable modifier can also improve the performance and economic sustainability of bituminous mixtures. Bitumen, a binder made from refined

crude oil, is one of its most crucial components. Environmental harm results from bitumen production's carbon dioxide emissions (Sharma *et al.*, 2022). Nevertheless, although several commercial modifiers can improve bituminous performance, the cost-benefit ratio of bitumen blends' is decreased when they are used. Therefore, the availability of alternative modifiers that can improve bitumen's qualities without increasing the cost of bitumen mixes or decreasing their cost-benefit ratio is crucial (Shuaibu *et al.*, 2021).

More specifically, bituminous materials are widely used in road construction around the world. These hydrocarbons can be found in nature or as a byproduct of distilling crude oil. The two types of bituminous materials used in highway construction are tars and asphalts (Syрманова *et al.*, 2017). Modified bitumen and the regeneration of old bitumen not only help with the safe disposal of RAP waste but also reduce the consumption of limited and non-renewable resources, which makes them more desirable in terms of global sustainability. According to several publications, 15% WEO should be used while producing HMA (Mamun and Al-Abdul Wahhab, 2018; Khan *et al.*, 2021).

Despite these individual applications, previous studies had investigated RAP recycling, LDPE modification, Waste Cooking oil (WCO) (Rodrigues *et al.*, 2020) and Waste Engine Oil rejuvenation (WEO) (Maharaj and Maharaj, 2015) largely as separate approaches. However, there remains a need to evaluate their combined application in high-RAP HMA, particularly to determine suitable RAP–LDPE combinations while using WEO to rejuvenate the aged RAP binder. Therefore, the present study examines the potential applications of RAP–LDPE combinations with Waste Engine Oil (WEO) as a rejuvenating agent in high RAP HMA.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials used in this study comprised 60/70 penetration-grade bitumen, low-density polyethylene (LDPE), waste engine oil (WEO), virgin coarse and fine aggregates, mineral filler and reclaimed asphalt pavement (RAP).

2.1.1 Bitumen

60/70 penetration grade bitumen was utilized in the production of the Hot Mix Asphalt. The bitumen was sourced from one of the operational locations of Julius Berger Nigeria Plc construction company located along Kaduna-Zaria Road.

2.1.2 Low-Density Polyethylene (LDPE)

The LDPE flakes with a density of 0.91 to 0.93 g/cm³ and melting point of about 100-125°C was utilized to modify the bitumen. The flakes were sourced from open dumps in Samaru area. They were washed, dried and shredded to produce the required size for the bitumen modification.

2.1.3 Waste Engine Oil (WEO)

The Waste Engine Oil (WEO) utilized in the study is the conventional used engine oil sourced from mechanic workshop in Samaru, Zaria Kaduna state.

2.1.4 Mineral Aggregates

Coarse and Fine Aggregates were obtained from a nearby quarry in Zango, Zaria, Kaduna state, Nigeria. Sieve Analysis was carried out on the aggregates to determine their particle size distributions. The particles retained on 4.75mm and 0.075mm were used as Coarse and Fine aggregates respectively in the production of the HMA.

2.1.5 Mineral Filler

Quarry dust obtained from a nearby Zango quarry in Zaria was used as the mineral filler. Sieve Analysis was carried out to determine the particle distribution of the quarry dust. The particles that passed through a 0.075 mm sieve was used in the production of the HMA.

2.1.6 Reclaimed Asphalt Pavement (RAP)

The RAP utilized in the research was obtained from one of the operational locations of Julius Berger Nigeria Plc construction company stockpiled by the roadside along Zaria-Kaduna Road in Dumbin Dutse. It was milled to achieve the required particle sizes of the RAP, the particles retained on 4.75mm sieve was utilized. The RAP was used as a partial to complete replacement for virgin coarse aggregate in the production of the HMA.

2.2.0 Characterization of the Constituent Materials

The constituent materials were characterized through laboratory testing to determine their physical properties and establish their suitability for asphalt mixture production. The laboratory tests were conducted at the Department of Civil Engineering Ahmadu Bello University, in accordance with the applicable standards.

2.2.1 Bitumen

The bitumen was characterized by conducting specific gravity, flash and fire point, ductility, softening point, and penetration tests in accordance with ASTM D70, ASTM D92, ASTM D113, ASTM D36, and ASTM D5, respectively.

2.2.2 Waste engine oil (WEO)

WEO is a dark brown or black liquid with varying properties depending upon type and utilization. The temperature determines its state, which is usually liquid and lighter than water (Mehmood *et al.*, 2024). Based on the previous studies of DeDene. (2011), metals such as lead, zinc, calcium, and magnesium were found in the used engine oil. Consequently, the WEO was filtered to remove the unwanted solid particles without carrying out any treatment on it. It was used as a rejuvenating agent to restore or soften the aged binder contained in the RAP. A WEO content equivalent to 15% by weight of the optimum binder content was incorporated into the asphalt mixture

2.2.3 LDPE-Modified Bitumen Preparation

LDPE is a thermoplastic polymer widely available from post-consumer plastic waste. When incorporated into asphalt binder, it forms a dispersed polymer-rich phase that improves stiffness and elastic recovery (Ling *et al.*, 2019; Fathi *et al.*, 2026). Because LDPE has a melting temperature of approximately 105–120°C, which is lower than the blending temperature of bitumen, it was incorporated using the wet-mixing technique (Ahmad and Ahmad, 2022). Prior to modification, the LDPE was cleaned, shredded into small pieces, and dissolved in kerosene on a heating pan at a controlled temperature to facilitate blending. The required quantity of conventional bitumen was gradually heated to $170 \pm 5^\circ\text{C}$ and maintained at this temperature throughout the process. Predetermined LDPE contents of 4%, 8%, and 12% by weight of the optimum binder content were then gradually added to the heated bitumen under continuous mechanical agitation. The mixture was maintained at $170 \pm 5^\circ\text{C}$ and mixed continuously for 60 minutes to promote the softening, dispersion, and uniform distribution of LDPE within the bitumen matrix, while avoiding excessive heating. A 15% waste engine oil (WEO), by weight of optimum binder content, was also added as a rejuvenator for the aged binder in the reclaimed asphalt pavement (RAP). The resulting homogeneous LDPE-modified binders were subsequently used to prepare asphalt mixtures containing the specified proportions of virgin aggregate and RAP.

2.2.4 Mineral aggregates

The virgin aggregates, both coarse and fine aggregates, were characterized through particle-size distribution, specific gravity, aggregate impact value (AIV), aggregate crushing value (ACV) and water absorption tests, conducted in accordance with, ASTM C136, ASTM C127, ASTM C535, ASTM C535, and ASTM C127, respectively.

2.2.5 Mineral Filler

The mineral filler was characterized through particle-size distribution and specific gravity tests, conducted in accordance with, ASTM C136, and ASTM C127 respectively.

2.2.6 Reclaimed Asphalt Pavement (RAP)

The RAP was characterized using sieve analysis, specific gravity, aggregate impact value, aggregate crushing value and water absorption tests. These tests were conducted in accordance with ASTM C136, ASTM C127, ASTM C535, ASTM C535 and ASTM C127 respectively.

2.2.7 Marshall Mix Design

The Marshall mix-design procedure, in accordance with ASTM D6927, was used to determine the optimum binder content (OBC) of the control asphalt mixture designed for heavy-traffic conditions. Control specimens comprising virgin aggregates and conventional bitumen were prepared at binder contents of 5-7% at 0.5% increments. Marshall stability, flow, bulk density, air voids (VIM), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) were evaluated. The OBC was selected based on the binder contents corresponding to maximum stability, maximum bulk density, and the specified air-void requirement; consequently, an OBC of 6.5% was obtained for the control mixture.

Subsequently, reclaimed asphalt pavement (RAP) was incorporated at replacement levels of 25-100% at an interval of 25% while LDPE was added at 4-12% at an interval of 4% by weight of bitumen. A full-factorial experimental design was developed using Design-Expert software version 13 to assess the combined effects of RAP and LDPE contents on the Marshall and volumetric properties of the asphalt mixtures. The design comprised 36 experimental runs. For each mixture, the constituent materials were thoroughly blended and compacted using 75 Marshall blows on each face of the specimen, in accordance with the requirements for a heavy-traffic wearing course.

3.0 RESULTS AND DISCUSSIONS

3.1 Bitumen

The results of the physical property tests, presented in Table 1, indicate that the bitumen is 60/70 penetration grade and has a specific gravity of 0.98. All the results of the carried-out tests fell within the specified limits of the relevant standards with the exception of softening point result in which there is an observed slight deviation from the standard which might have been due to human error when conducting the test. These results confirm the suitability of the bitumen for use in the production of Hot Mix Asphalt (HMA).

Table 1: Tests and Code Limits on Bitumen

Tests	Results	Specifications	Code
Fire test ($^{\circ}\text{C}$)	355	Min. 232	ASTM D92
Ductility at 25 $^{\circ}\text{C}$, cm	110	Min. 100	ASTM D113
Softening point ($^{\circ}\text{C}$)	*57.5	48-56	ASTM D36
Penetration at 25 $^{\circ}\text{C}$ (0.1mm)	64	60-70	ASTM D5
Specific gravity test at 25 $^{\circ}\text{C}$	0.98	0.97-1.02	ASTM D70
Flash test ($^{\circ}\text{C}$)	325	Min. 232	ASTM D92

*Asterisk indicates a slight deviation in softening point result from the code specification

3.2 Mineral Aggregates

The results presented in Tables 2 and 3 show that the coarse aggregate recorded an ACV of 23.10%, an AIV of 25.97%, and a specific gravity of 2.85, while the fine aggregate had a specific gravity of 2.64. The obtained results satisfied the requirements specified by the relevant standards for mineral aggregates, indicating that the virgin aggregates were suitable for use in the production of the HMA.

Table 2: Tests and Code Limits on Coarse Aggregates

Tests	Results	Limitations	Code
Sieve analysis	Cu>1<3, Cc<1		ASTM C136
Specific gravity	2.85	Max. 3	ASTM C127
Aggregate impact value (%)	25.97	Max. 30	ASTM C535
Aggregate crushing value (%)	23.10	Max. 30	ASTM C535
Absorption test (%)	0.4	Max. 5	ASTM C 127

Table 3: Tests and Code Limits on Fine Aggregates

Tests	Results	Limitations	Code
Specific gravity	2.64	2.50-3.00	ASTM C127
Sieve analysis	Cu>3, Cc>1<3		ASTM C136

3.3 Reclaimed Asphalt Pavement (RAP)

Table 4 displays the results of the physical characteristics tests conducted on Reclaimed Asphalt (RAP). The reclaimed asphalt's specific gravity, ACV, and AIV are 2.56, 26.00, and 23.00, respectively. The RAP is suitable for use in asphalt mixtures because they fall within the specified ranges in ASTM Standards.

Table 4: Tests and Code Limits on RAP

Tests	Results	Limitations	Code
Specific gravity	2.56	3max	ASTM C127
Aggregate impact value (%)	26.00	30max	ASTM C535
Aggregate crushing value (%)	23.00	30max	ASTM C535
Absorption test (%)	0.40	0.5max	ASTM C127

3.4 Combined Aggregate Curve

The centre curve displays the mix derived from the findings of the particle size distribution test conducted on the mineral aggregates utilized in this investigation, while the upper and lower curves are as specified in the applicable code for use in asphalt. This implies that the mixed aggregate will have a strong interlocking and an appropriate packing density to support loads and withstand deformation as supported by (Shuaibu *et al.* 2024). The results of the combined particle size analysis, as displayed in Figure 1, indicate that the aggregates are suitable for use in HMA since the test results fell between the upper and lower boundary limits (FMWH, 2016).

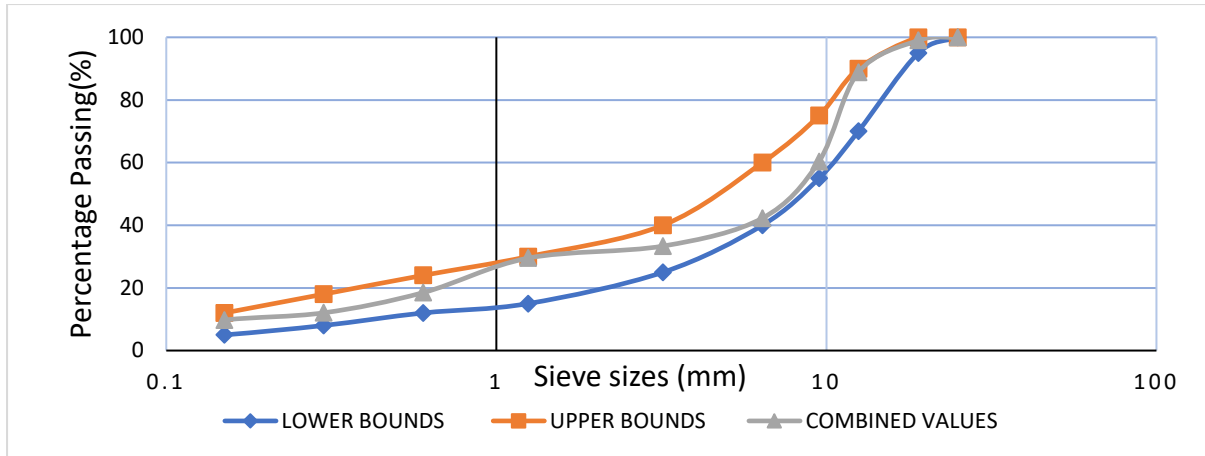


Figure 1: Combined curve for mineral aggregates

3.5 Marshall Mix Design - Optimum Bitumen Content

The asphalt contents having the maximum value of bulk density, Marshall Stability and median air void are selected. The bitumen content at median numerical values for approximately 7% air void, maximum stability and maximum bulk density are 6.5%, 6% and 7% respectively. The optimum bitumen content of 6.5% was determined by taking the average value of the selected properties in accordance with the Nigerian general specification code for roads and bridges which satisfies the requirements for surface course of 5-8%.

$$\text{OBC (\%)} = \frac{\text{Maximum Stability}(\%BC) + \text{Maximum bulk density}(\%BC) + \text{Median VA}(\%BC)}{3}$$

$$= \frac{6.0 + 7.0 + 6.5}{3} = 6.5\%$$

Table 5: Marshall Property Test carried out on HMA samples

Bitumen Content (%)	Stability (kN)	Flow (mm)	Bulk Density (g/cm ³)	Quotient (kN/mm)	VMA (%)	VFB (%)	VA (%)
5.0	4.90	4.90	2.08	1.00	21.06	52.52	10.00
5.5	6.40	4.60	2.13	1.39	21.10	53.46	9.82
6.0	7.60	3.70	2.15	2.05	20.05	59.50	8.12
6.5	6.60	3.90	2.10	1.69	19.74	63.12	7.28
7.0	5.90	3.20	2.21	1.84	21.26	59.78	8.55

3.6 Analysis of the Effect of LDPE and RAP to Marshall and Volumetric Parameters

The results of the Marshall and volumetric Analysis of sample with varying RAP and LDPE contents are presented in the figures below.

3.6.1 Stability

Stability is the maximum load needed to cause failure of a specimen upon application of load. The stability of the LDPE-modified asphalt mix with respect to the amount of RAP and LDPE wastes is depicted in Figure 2. The chart peaks at 8.28kN stability represents 50% RAP and 12% LDPE waste. Continuously, until it reached 50% RAP content, the stability of the modified asphalt mix rose in step with the RAP level; after that, stability started to decline at higher bitumen content. This decrease in

stability revealed that increasing bitumen content creates too thick film on the aggregate particles, resulting in loss of inter-particle friction and this leads to insufficient stability in pavements (Genet *et al.*, 2021). However, as a saturation point was reached at 50% RAP, stability started to decline. Previous research indicates that the stability of the mix increases with the quantity of LDPE in HMA until a certain point, beyond which it begins to decrease as the amount of plastic grows (Akinpelu *et al.*, 2013). Although the peak stability was recorded at 50% and 12% LDPE modification, all the values recorded at different RAP contents and LDPE modifications exceeded the Nigerian minimum limits of 3.5kN.

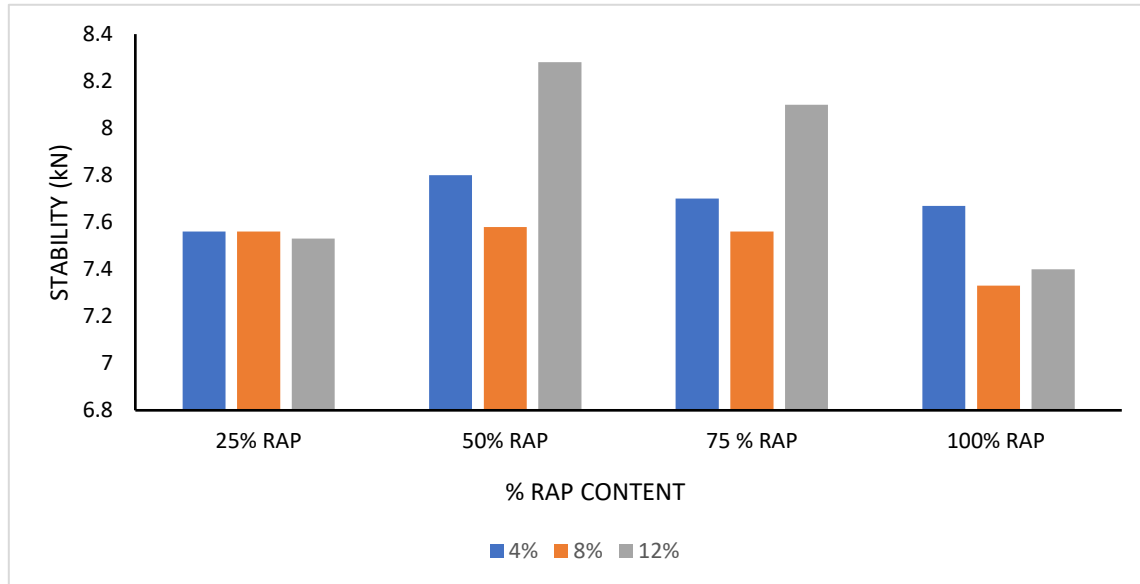


Figure 2: Relationship between the stability and the RAP content at different LDPE modifications.

3.6.2 Flow

The relationship between the flow in the asphalt mix sample and the RAP/LDPE waste concentration is shown in Figure 3. There is observed increase in the flow of the LDPE-modified bitumen at lower LDPE waste content and continuously increased until it reached a maximum value of 3.56mm, then it started decreasing at higher LDPE/RAP wastes content. The decrease in flow of the marshal mix as the waste LDPE content increase also shows that the increase in resistance to rutting. Higher flow value shows higher flexibility while lower flow value shows higher rigidity (Jassim *et al.*, 2014; Kotresh *et al.*, 2016; Genet *et al.*, 2021). As observed from the chart, the optimal flow of 3.56 mm is achieved with 50% RAP and 8% LDPE waste. The outcome of the flow is between 2-4mm, falling within the FMWH general parameters' range. This illustrates how well LDPE reduces flow, enhancing the capacity of the asphalt to support loads. A higher flow value denotes more flexibility, whereas a lower flow value denotes more stiffness (Genet *et al.*, 2021).

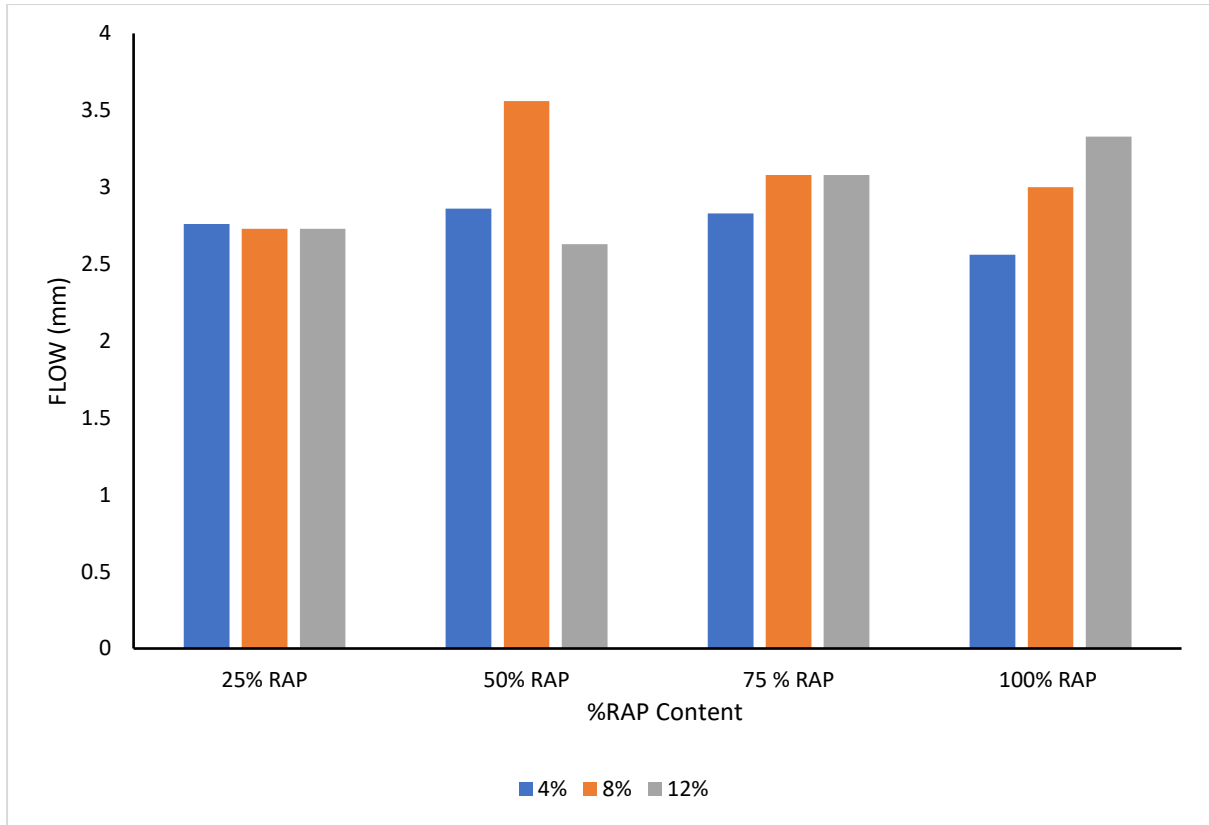


Figure 3: The Relationship between the flow and the RAP content at different LDPE modifications

3.6.3 Marshall Quotient

Figure 4 shows the relationship between the RAP/LDPE waste contents and the asphalt marshall quotient. The overall stiffness and viscosity of the asphalt mixture reduced as the bitumen concentration rose, which caused the quotient to decline as the RAP percentage rose. At 4% LDPE waste and 100% RAP, the quotient peaks at 2.99 kN/mm. This result is in line with another study's conclusions (Kotresh *et al.*, 2016).

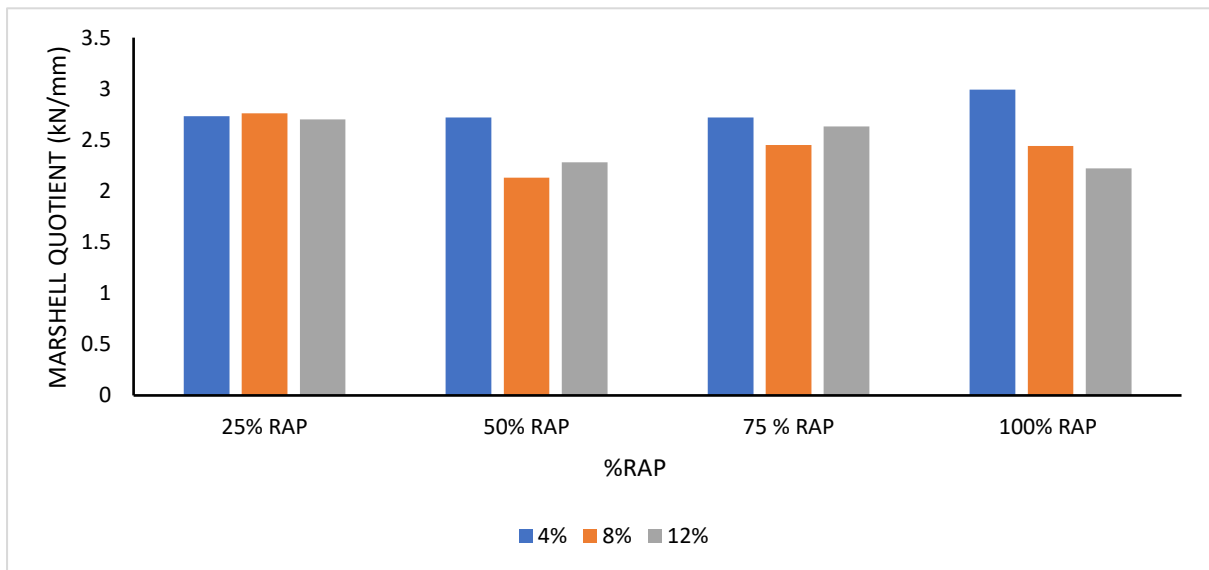


Figure 4: The Relationship between the Quotient and the RAP content at different LDPE modifications

3.6.4 Bulk Density

The relationship between Bulk Density and RAP at various LDPE modifier contents is shown in Figure 5. The addition of material having a lower specific gravity than the base material results in a drop in the bulk density of the compacted mixes as the RAP content rises; in other words, the increase in LDPE content causes the decrease. The variation in the density values from 2.22-2.25 g/cm³ shows minimal variation confirming stable compaction behavior which is in line with the study conducted by (Fadhil et al., 2026).

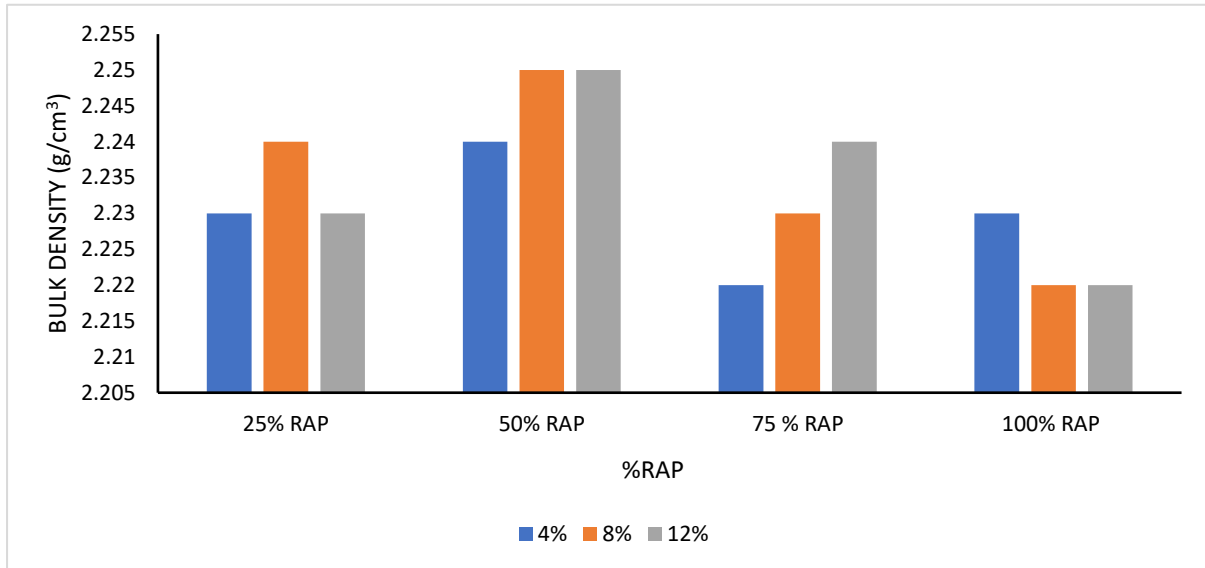


Figure 5: Relationship between Bulk Density and RAP at different LDPE modifier contents.

3.6.5 Voids in Mineral Aggregate

The void in the mineral aggregate (VMA) is defined by the intermolecular spaces between the aggregate particles in compacted paving mixtures that includes the air voids and the effective asphalt content (Genet et al, 2021). The correlation between VMA and RAP at varying LDPE modifier levels (25, 50%, 75%, and 100%) of RAP is depicted in Figure 6. The number of voids that can be filled with asphalt binder is indicated by the presence of voids in mineral aggregates with a numerical value of 22.2% void in mineral aggregate. The highest VMA was achieved at 75% RAP and 4% LDPE waste content. According to the applicable usage standards for asphalt mix, this result falls within the ideal range for VMA. The gaps between the particles have been successfully filled in and partially sealed by the LDPE.

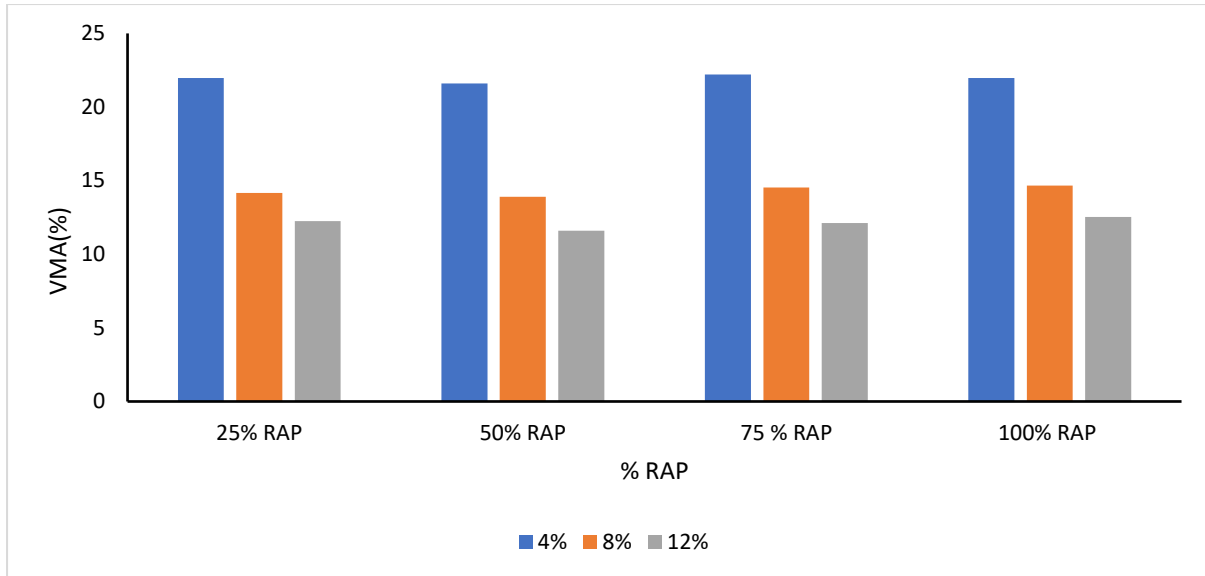


Figure 6: The relationship between VMA and RAP at different LDPE modifier content

3.6.6 Voids Filled with Bitumen

Figure 7 illustrates the link between VFB and RAP at different LDPE modifier contents. The findings indicated that when the RAP and LDPE contents increase, the VFB value decreases. The chart indicates that the ideal bitumen-filled void was found at 50% RAP and 12% LDPE waste content, which is equivalent to 53% VFB. The VFB values of the modified mix are higher than those of the control mix. The observed reduction at 100% RAP further suggests that the influence of LDPE waste becomes more significant as the proportion of aged RAP materials increases. The reduction in VFB at higher RAP and LDPE contents may be associated with changes in binder rheology and aggregate-binder interaction, which could eventually influence aggregate packing, compaction and air-void development. The maximum VFB is 53%, which is less than the 75-85% required value of the Nigerian general standard for roads and bridges indicating that the mixtures contained a relatively low proportion of effective binder within the available voids in the mineral aggregate. This suggests that the mixtures may have relatively high air-void contents and/or inadequate filling of the aggregate void structure. From an engineering perspective, excessively low VFB may result in a mixture that is relatively dry and potentially more susceptible to permeability, oxidation and moisture-related deterioration, thus, poor durability.

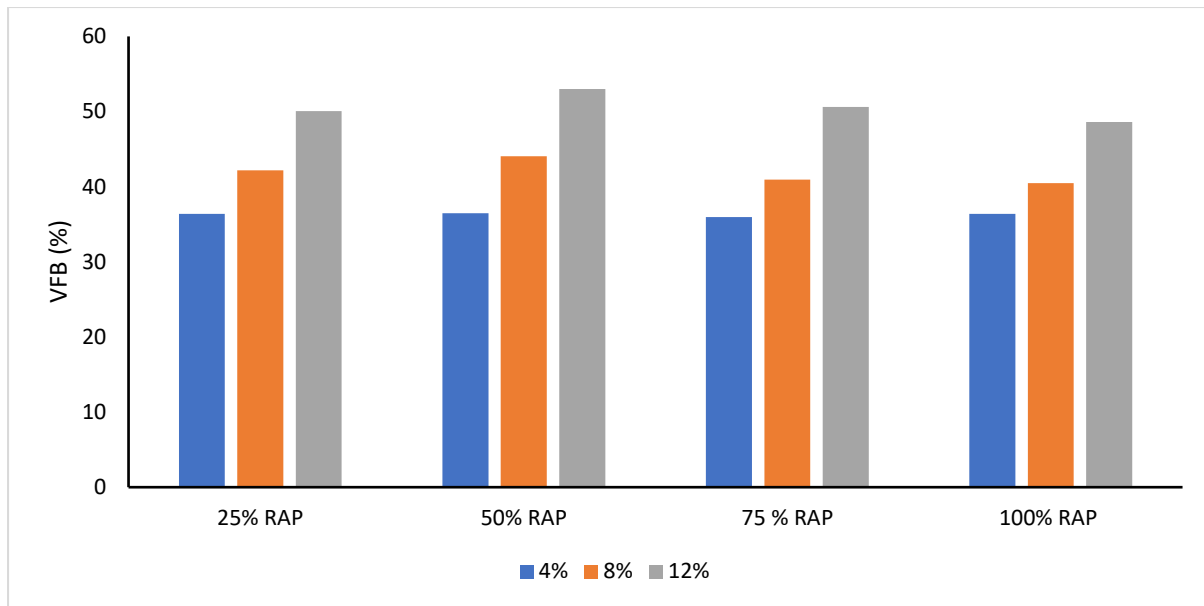


Figure 7: The relationship between VFB and RAP at different LDPE modifier content

3.6.7 Air Voids

It is the total volume of air (VA), expressed as a percentage of the bulk volume of the compacted mixture, which is distributed throughout a compacted paving mixture and is located between the coated aggregate particles (Genet et al, 2021). The relationship between the quantity of RAP/LDPE waste in the asphalt and the air voids in the asphalt mix is shown in Figure 8. The maximum air void, which corresponds to 75% RAP and 4% LDPE waste, is found at 14.27%. The VA results indicated that all the investigated HMA mixtures exceeded the specified VA range of 3–5%, with values ranging from approximately 5.46% to 14.27%. The relatively high VA contents suggest that the mixtures did not achieve adequate densification during compaction. The increase in RAP content introduces aged and relatively stiff binder into the mixture, while LDPE modification can further alter binder stiffness and workability. Although a fixed amount of WEO was incorporated as a rejuvenator, its constant dosage may have been insufficient to counteract the increasing influence of aged RAP binder and LDPE modification at higher RAP contents. Consequently, the binder might have had limited workability during mixing and compaction, resulting in inadequate aggregate packing and retention of excessive air voids. The high air-void contents are also consistent with the relatively low VFB values obtained in the study. From a pavement performance perspective, excessive air voids can increase permeability and accelerate oxidative ageing and moisture-related deterioration, thereby reducing the durability and service life of the HMA. Therefore, the investigated mixtures, in their present formulation, do not satisfy the specified volumetric requirement and require further optimization of the binder content, LDPE level, WEO dosage, aggregate gradation and compaction conditions.

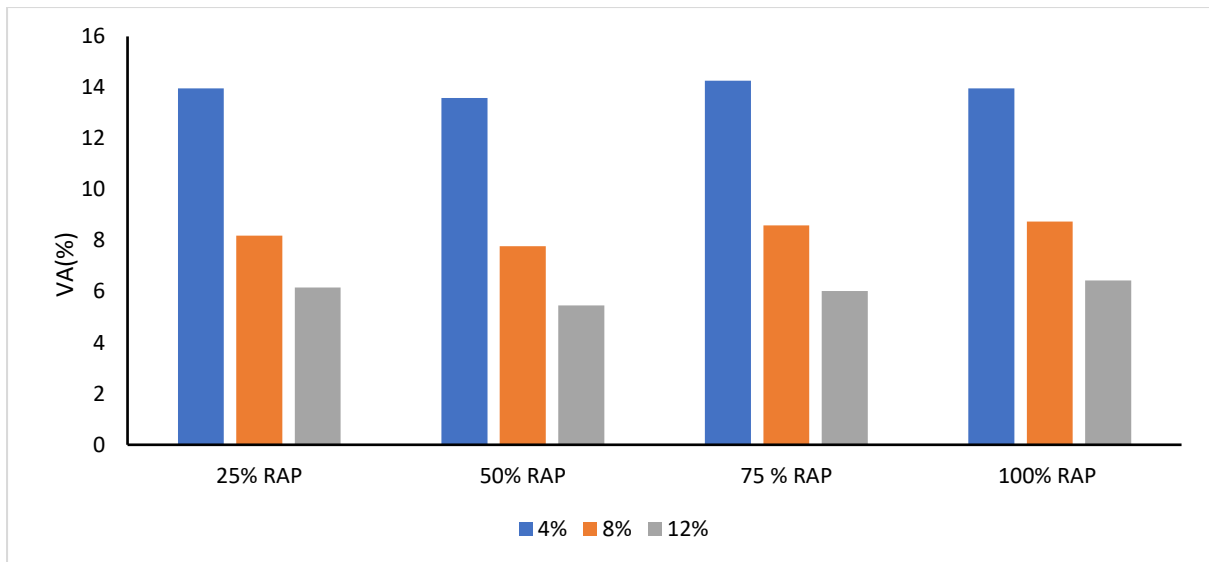


Figure 8: The relationship between VA and RAP at different LDPE modifier content

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The effects of different percentages of RAP and LDPE waste on the mechanical and physical characteristics of HMA were investigated in this study using Waste Engine Oil (WEO) as a rejuvenating agent in the mix. The followings were deduced from the research;

- a. By satisfying all the specifications of the physical property tests provided in the standards, the results demonstrate that the asphalt mix is suitable for pavement construction. This indicates the component materials can withstand applied stress, which raises the possibility of long-term pavement performance. However, the results of the volumetric properties show that the mixture formulation still needs further volumetric optimization.
- b. Following a careful analysis of the Marshall test results on the control mix, the Optimum Binder Content (OBC) of the mixture was found to be 6.5%. This value balances stability, flow and voids to ensure superior pavement performance while minimizing problems related to excess bitumen and ensuring optimal binding and lifespan.
- c. Marshall properties with stability 8.28kN ($> 3.5\text{kN}$) and flow value of 3.56mm (2-4mm) satisfied the requirement while the volumetric properties of the HMA other than VMA of 22.2% ($>13\%$) did not meet requirements. Consequently, further optimization of the volumetric properties should be carried out.

4.2 Recommendations

According to the findings of the research, further study should be carried out to examine the long-term pavement performance of the HMA as well optimization of the volumetric properties, particularly under various traffic loading and climatic circumstances.

5.0 REFERENCES

- Ahmad, M. S., & Ahmad, S. A. (2022). The impact of polyethylene terephthalate waste on different bituminous designs. *Journal of Engineering and Applied Science*, 69(1), 53.
- Akinpelu, M., Dahunsi, B. I. O., Olafusi, O., Awogboro, O., & Quadri, A. (2013). Effect of polythene modified bitumen on properties of hot mix asphalt. *ARP Journal of Engineering and Applied Sciences*, 8(4), 290–295
- Arianto, H., Saleh, S. M., & Anggraini, R. (2019). Karakteristik Campuran Ac-Wc Menggunakan Material Reclaimed Asphalt Pavement Dengan Tambahan Aspal Pen. 60/70 Yang Disubstitusi Styrofoam. *Jurnal Arsip Rekayasa Sipil dan Perencanaan*, 2(2), 149-157.
- ASTM C127-15. (2015) Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate, ASTM International, West Conshohocken, PA.
- ASTM C535 – 09. Standard Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, 2009.
- ASTM D113. (2007) Standard test method for ductility of bituminous materials, Annual Book of Standards
- ASTM D36. (2009) Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), ASTM International, West Conshohocken, PA, USA.
- ASTM D5. (2013) Standard test method for penetration of bituminous materials. USA, ASTM International.
- ASTM D6927-15: Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures, ASTM International. West Conshohocken, PA (2015)
- ASTM D70. (2003) Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method), ASTM International, West Conshohocken, PA.

- ASTM D92. (2015) Standard test method for flash and fire points by Cleveland open cup tester, Annual Book of Standards.
- ASTM International. (2025). *ASTM C136/C136M-25: Standard test method for sieve analysis of fine and coarse aggregates*. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/C0136_C0136M-25
- Cheraghian, G., Falchetto, A. C., You, Z., Chen, S., Kim, Y. S., Westerhoff, J., ... & Wistuba, M. P. (2020). Warm mix asphalt technology: An up-to-date review. *Journal of cleaner production*, 268, 122128.
- DeDene, C. D. (2011). *Investigation of using waste engine oil blended with reclaimed asphalt materials to improve pavement recyclability*. Michigan technological university.
- Ezeudu, O. B., Tenebe, I. T., & Ujah, C. O. (2024). Status of production, consumption, and end-of-life waste management of plastic and plastic products in Nigeria: Prospects for circular plastics economy. *Sustainability*, 16(18), 7900.
- Fadhil, A., Ismy, R., Khairunnisa, H., & Suhaimi. (2026). Integrated mechanical and volumetric evaluation of plastic modified RAP mixtures using Marshall parameters. *Engineering and Technology Journal*, 11(3), 9138–9145. <https://doi.org/10.47191/etj/v11i03.01>
- Fathi, A., Moussa, G. S., & Abd Elshafy, Z. I. (2026). High-RAP asphalt mixtures using waste engine oil rejuvenation and recycled polymer reinforcement: A critical review toward integrated performance-based design. *Port Said Engineering Journal*. Advance online publication. <https://doi.org/10.21608/pej.2026.468271.1039>
- Federal Ministry of Works Nigeria (FMWH), (2013). Compendium report on road infrastructure and related development- an investor's manual. Retrieved from <http://www.works.gov.ng/pdf>
- FMWH. (2016) Nigerian General Specifications for Roads and Bridges, FEDERAL MINISTRY OF WORKS AND HOUSING, in: F. R. O. N. FEDERAL MINISTRY OF WORKS AND HOUSING (Ed.).
- Genet, M. B., Sendekie, Z. B., & Jembere, A. L. (2021). Investigation and optimization of waste LDPE plastic as a modifier of asphalt mix for highway asphalt: Case of Ethiopian roads. *Case Studies in Chemical and Environmental Engineering*, 4, 100150.
- Hunter, R. N., Self, A., Read, J., & Hobson, E. (2015). *The shell bitumen handbook* (Vol. 514). London, UK:: Shell Bitumen.
- Jassim, H. M., Mahmood, O. T., & Ahmed, S. A. (2014). Optimum use of plastic waste to enhance the Marshall properties and moisture resistance of hot mix asphalt. *International Journal of Engineering Trends and Technology*, 7(1), 18-25.
- Khan, M. Z. H., Koting, S., Katman, H. Y. B., Ibrahim, M. R., Babalghaith, A. M., and Asqool, O. (2021). Performance of high content reclaimed asphalt pavement (RAP) in asphaltic mix with crumb rubber modifier and waste engine oil as rejuvenator. *Applied sciences*, 11(11), 5226.
- Khurshid, I., & Kumar, N. (2021). A study on replacement of bitumen partially with waste cooking oil and engine oil in bituminous concrete. *International Journal of Research in Engineering, Science and Management*, 4(5), 204-213.
- Kotresh, K. M., Kebede, Y. B., Bhavya, R., & Vageesh, H. P. (2016). A study on use of plastic wastes in road pavement construction. *International Journal of Innovative Research in Science, Engineering and Technology*, 5(4), 5955-5961.
- Ling, M., Chen, Y., Hu, S., Luo, X., & Lytton, R. L. (2019). Enhanced model for thermally induced transverse cracking of asphalt pavements. *Construction and building materials*, 206, 130-139.
- Maharaj, R., & Maharaj, C. (2015). Physical properties of low density polyethylene, polyvinylchloride and used engine oil modified asphalt. *Progress in Rubber Plastics and Recycling Technology*, 31(3), 173-187.
- Mamun, A. A., & Al-Abdul Wahhab, H. I. (2018). Evaluation of Waste Engine Oil-Rejuvenated Asphalt Concrete Mixtures with High RAP Content. *Advances in Materials Science and Engineering*, 2018(1), 7386256.

- Martinho, F. D. C. G., Picado-Santos, L. G., & Capitão, S. D. (2018). Feasibility assessment of the use of recycled aggregates for asphalt mixtures. *Sustainability*, 10(6), 1737.
- Mehmood, R., Jakarni, F. M., Muniandy, R., Hassim, S., Nik Daud, N. N., & Ansari, A. H. (2024). *Waste engine oil as a sustainable approach for asphalt rejuvenation and modification: A review*. *Heliyon*, 10(23), e40737. DOI: 10.1016/j.heliyon.2024.e40737.
- Mohod, M. V., & Kadam, K. N. (2016). A comparative study on rigid and flexible pavement: A review. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 13(3), 84-88.
- Nizamuddin, S., Boom, Y. J., & Giustozzi, F. (2021). Sustainable polymers from recycled waste plastics and their virgin counterparts as bitumen modifiers: A comprehensive review. *Polymers*, 13(19), 3242.
- Onuche, I., Oji, A., & James, B. N. (2024). Techno-economic potential and policy review of used engine oil re-refining in Nigeria. *International Research Journal of Modernization in Engineering Technology and Science*, 6(5), 3850–3857.
- Ozer, H., Al-Qadi, I. L., Carpenter, S. H., Aurangzeb, Q., Roberts, G. L., & Trepanier, J. (2009). Evaluation of RAP impact on hot-mix asphalt design and performance. *Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions*, 78, 317–348.
- Rodrigues, C., Capitão, S., Picado-Santos, L., & Almeida, A. (2020). Full recycling of asphalt concrete with waste cooking oil as rejuvenator and LDPE from urban waste as binder modifier. *Sustainability*, 12(19), 8222.
- Sharma, V. K., Kumar, R., & Singh, A. P. (2022). Laboratory investigation of bituminous concrete using Reclaimed asphalt pavement and waste Engine oil. *Materials today: proceedings*, 59, 1591-1598.
- Shuaibu, A. A., Sulaiman, T. A., Bakare, S. M. A., Hafiz, B., Otuoze, H. S., & Amodu, I. M. (2024). Marshall properties of hot mix asphalt containing municipal solid waste incinerator (MSWI) bottom ash as filler aggregate. *Nigerian Journal of Engineering*, 31(3), 59–66.
- Shuaibu, A., Mohammed, A., Hassan, U., Amartey, B., Wada, S., Mohammed, A., & Rimi, A. (2021). An experimental study on the performance of bituminous concrete mixtures with silica sand as filler replacement. *Arid Zone Journal of Engineering, Technology and Environment*, 17(4), 453-468
- Syrmanova, K. K., Botashev, E. T., Tleuov, D. B., Suleimenova, M. T., Eshankulov, A. A., & Kaldybekova, Z. B. (2017). Research of oil road bitumen modification with low density polyethylene. *Oriental Journal of Chemistry*, 33(1), 470-477.